COMPRESSIONAL FLOW RIDGES: IMPLICATIONS FOR ANALYSIS OF PLANETARY LAVA FLOWS.

Jeffrey M. Byrnes[1], David A. Crown[1], Jeffrey J. Plaut[2], and Steven W. Anderson[3]. *[1]Department of Geology and Planetary Science, University of Pittsburgh, Pittsburgh, Pennsylvania 15260-3332, [2]Jet Propulsion Laboratory, 4800 Oak Grove Drive, Pasadena, California 91109, [3]Department of Physical Science, Black Hills State University, Spearfish, South Dakota 57799-9102*

Introduction

Compressional ridges are features indicative of surface folding that occurs during lava flow emplacement [1-3]. Folding theory, as developed by Fink and Fletcher [1], provides a theoretical framework for analyzing flow rheology based on ridge geometry. Their model was developed specifically to describe ridges observed on terrestrial ropy pahoehoe basalt flows [1], which typically display ridge spacings of about 10 centimeters [2,3] and amplitudes on the order of a few centimeters [1,3]. The model was also applied to rhyolite flows, which typically display ridge spacings of tens of meters and amplitudes on the order of ten meters [2,3]. Other investigators have applied the folding model to flows in a variety of different environments, including flows on Mars [3,4] and Venus [5]. Martian flows exhibit a wide range of ridge geometry, with spacings of 700 m [3] and 7 to 194 m [4] and amplitudes of 50 m [3] and 10 to 50 m [4] for various flows. One Venusian flow displays ridge spacings of 625 to 770 m [5]. In this study, compressional ridges on terrestrial silicic lava flows were investigated to determine the detectability of ridges using various techniques and to ascertain the applicability of folding theory to these flows.

Methodology

Ridges are dominant surface features on many terrestrial silicic lava domes [6] and their distribution, spacing, and amplitude are indicative of flow emplacement history and surface deformation. Terrestrial silicic domes are a potential analog for steep-sided domes on Venus [7,8], so it is important to understand the implications of ridge structures in different eruptive settings. For this purpose, ridges were studied on Obsidian Dome, Glass Creek Dome, and Deadman Dome (three of the Inyo Domes located in Long Valley, California [9]), and Big Glass Mountain (located on the Medicine Lake Highland Volcano, California [10]). Ridge structures were analyzed using stereo pairs of aerial photographs, field data [6,11,12], and airborne synthetic aperture radar (AIRSAR) data. Ridges in the aerial photographs were identified by their elongated shape and raised topographic expression, sometimes accentuated by variations in lava texture at the surface of the flow. Ridges on the domes commonly occur in sets of sub-parallel arcs that coalesce at the edges; this morphology is characteristic of flow lobes radiating out from a central vent region, and indicates a complex emplacement history. Anderson et al. [6] illustrate the distribution of regions that display ridged surface morphology on each of the silicic flows studied. Ridge spacings were determined by mapping the intersection of ridge crests with transects parallel to the direction of surficial shortening. Aerial photograph scales are ~1:17,800 for the three Inyo Domes and ~1:31,400 for Big Glass Mountain. Ridge spacings were compared to the spacing apparent in topographic field measurements made by Anderson et al. [6,11,12] who surveyed topographic variations at 25 cm increments along orthogonal transects at various sites on the domes. Although some ridges are difficult to recognize in the field (due to the extremely blocky nature of silicic domes [13]), they are apparent in the topographic field measurements. AIRSAR data was acquired at 5.7, 24, and 68 cm wavelengths for incidence angles of 24-37, 33-43, and 46-53 degrees. Single wavelength black and white images and three color composite images were generated to assess ridge detectability. Resolution of the AIRSAR data is 10 m/pixel.

Detectability of Ridges

Based on stereo analysis of aerial photographs, ridge spacings on the domes range from 9 to 141 m [see Table I] and in many cases appear to decrease in a regular fashion from the vent region toward the margin. The ridge spacings evident in the field data vary from 13 to >32 m at five sites on the Inyo Domes. These sets of measurements raise a significant question as to the detectability of ridges using various techniques. In some cases, not all ridges are discernible on the aerial photographs. In other cases, the field data obtained suggest that smaller scales (and possibly multiple episodes) of folding (as described in [1] for basaltic pahoehoe flows) may have occurred; if this is true, the aerial photographs may only reveal the largest scale of ridges. Smaller scale folds may also be obscured on the silicic flows due to the extensive breccia carapace. Further field work is necessary to correlate analysis of field measurements and aerial photographs. Individual ridges cannot be clearly resolved on AIRSAR data, although regions that display ridged morphology, as identified in aerial photographs and confirmed by field studies, appear to be correlated with a distinctive texture on AIRSAR composite images.

Applicability of Folding Theory

Folding theory provides a quantitative method for analyzing the deformation of a uniform fluid whose viscosity decreases systematically with depth, is subject to a uniform rate of shortening, flows in a plane, and has a cylindrical surface. Terrestrial silicic lava flows differ from the theory's idealized fluid and from basaltic pahoehoe in a number of ways. Analysis of research drilling of rhyolite flows and field studies indicate that there are significant stratigraphic variations within individual extrusions due to different volatile concentrations [14]. This is particularly significant because Fink observed that ridge amplitude on rhyolite flows is greatest where lava density is lowest [2]. Furthermore, our measurements indicate that ridge spacings on a given flow appear to change with distance from the vent region, possibly indicating that the flow is not subject to a uniform rate of surface shortening. Surface shortening might occur at a uniform rate for planar flows, but for non-planar flows the folding model needs to incorporate the effects of variable topography on the relationship between gravitational and compressional stresses. Variations in ridge spacings seem to correlate roughly with changes in the slope of the flow surface, which indicates that perhaps the folding model may be applied to segments of a flow that have uniform surface slopes. Finally, ridged regions of the Inyo Domes appear to have spread radially from the vent region in one or more broad lobes producing a tensional force normal to compression in the horizontal plane. This effect is not incorporated into the two-dimensional folding theory model, nor is it typical of the basaltic pahoehoe flows studied, whose deformed ropy surfaces are found on crusts in channels which are laterally confined [1]. Use of folding theory for analysis of ridged planetary lava flows requires an understanding of limitations on ridge detectability and a site-specific evaluation of folding theory assumptions.

References: [1] Fink, J.H. and Fletcher, R.C., 1978. J. Volcanol. Geotherm. Res., 4, 151-170. [2] Fink, J.H., 1980. Geology, 8, 250-254. [3] Fink, J.H., 1980. Lunar Planet. Sci. Conf., XI, 285-287. [4] Theilig E., and Greeley, R., 1986. Proc. Lunar Planet. Sci. Conf., 17th, Part 1, J. Geophys. Res., 91, E193-E206. [5] Schenk, P., 1992. Lunar Planet. Sci. Conf., XXIII, 1217-1218. [6] Anderson, S.W., Stofan, E.R., Plaut, J.J., and Crown, D.A., 1997. Geology, to be submitted. [7] Pavri, B., Head, J.W., Klose, K.B., and Wilson, L., 1992. J. Geophys. Res., 97, E8, 13445-13478. [8] McKenzie, D., Ford, P.G., Liu, F., and Pettengill, G.H., 1992. J. Geophys. Res., 97, E10, 15967-15976. [9] Miller, C.D., 1985. Geology, 13, 14-17. [10] Donnely-Nolan, J.M., 1987. GSA Cent. Field Guide, Cordilleran Section, 289-294. [11] Anderson, S.W., Stofan, E.R., Plaut, J.J., and Crown, D.A., 1994. Lunar Planet. Sci. Conf., XXV, 33-34. [12] Anderson, S.W., Stofan, E.R., Plaut, J.J., and Crown, D.A., 1996. Lunar Planet. Sci. Conf., XXVII, 27-28. [13] Plaut, J.J., Stofan, E.R., Crown, D.A., and Anderson, S.W., 1994. Lunar Planet. Sci. Conf. XXV, 1091-1092. [14] Manley, C.R., and Fink, J.H., 1987. Geology, 15, 549-552.

Table I.

Location	**Transect**	**Population**	**Ridge Spacing**			
			Min (m)	**Max (m)**	**Mean (m)**	**Std Dev**
Obsidian Dome	A-A'	10	18	45	28.5	6.1
	B-B'	20	9	45	21.8	7.0
	C-C'	18	9	80	29.2	13.2
	D-D'	12	9	45	26.0	8.3
	E-E'	6	27	53	34.1	7.4
Glass Creek Dome	A-A'	7	9	36	15.3	5.8
	B-B'	3	9	36	29.7	7.9
	C-C'	5	18	89	40.9	11.0
Deadman Dome	A-A'	7	18	27	24.2	3.6
	B-B'	5	18	53	30.3	9.3
	C-C'	20	9	62	25.8	10.5
Glass Mountain	A-A'	48	16	126	45.5	15.6
	B-B'	27	16	63	36.6	9.3
	C-C'	21	16	141	55.3	28.1